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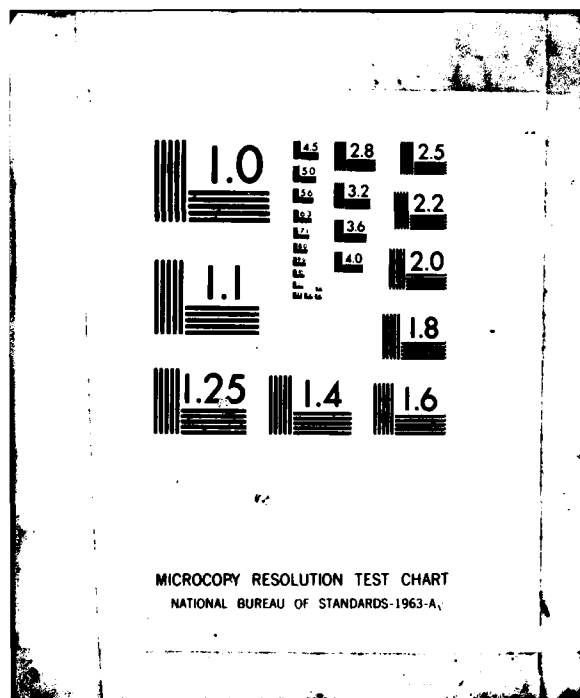
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The structural changes which occur during the aging and tempering of initially virgin iron-carbon martensites are briefly summarized, in terms of important contributions by the late Peter G. Winchell.		

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Opening of the  
PETER G. WINCHELL SYMPOSIUM ON THE TEMPERING OF STEEL\*  
Morris Cohen

On January 12th of this year (1981), exactly 9 months ago, Professor Peter Winchell passed away very suddenly. His valiant heart, having pulsed faithfully for over 51 years, stopped without warning while apparently in full vigor. At that moment, a grievous loss was suffered by his family, by his students young and old, and by the world-wide metallurgical profession. But there was something to be grateful for; we are told that the fatal instant came so quickly that he could not have experienced much pain, and we also know that there was no lingering illness.

Several months before his death, and working with George Krauss, Peter had started to organize a Symposium on the Tempering of Steel. In fact, he had accomplished most of the programming on this timely subject just before his untimely death. Gilbert Speich then joined forces with George Krauss as co-chairmen, and almost spontaneously it was decided not only to go ahead with the Symposium as planned but also to dedicate it as a memorial to Peter Winchell.

And so we find ourselves here in Louisville, under the auspices of The Metallurgical Society of AIME and in the presence of Peter's family, colleagues, and friends, to hold a two-day Symposium on the Tempering of Steel.

Peter Winchell received the AB degree from the University of Chicago in 1948, the SB degree in Metallurgy from MIT in 1953, and the

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\* Presented at the TMS-AIME Fall Meeting, 12-13 October 1981, Louisville, KY.  
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Ph.D. in Metallurgy from MIT in 1958. His doctoral thesis was on "The Structure and Mechanical Properties of Iron-Nickel-Carbon Martensites." It proved to be an historical piece of research, not only elegantly conceived and thoroughly conducted, but it opened the way for many more investigations at MIT, and likewise at Purdue University where Peter became Assistant Professor in 1958, Associate Professor in 1962, and full Professor in 1968. Over the years, the thesis research supervised by Peter Winchell has ranged from solid-state thermodynamics and kinetics, to diffusion, to quantitative metallography, to atomic configurations and displacements, to residual strains, and of course to mechanical behavior. But throughout his active career, spanning a quarter of a century, Peter remained dedicated to one central theme -- to unravel the mysteries of ferrous martensitic transformations and the tempering of ferrous martensites.

To point up his impact on this field, and in fact on this very Symposium, I shall refer here to only two of his landmark papers: the first from MIT in 1962<sup>(1)</sup>, and his almost-last paper from Purdue in 1980<sup>(2)</sup>. The 1962 paper was a "first" in several ways. Peter broke new ground in realizing that freshly quenched martensite ages very quickly at room temperature and it is already changed before the first measurements can be made. He neatly circumvented this difficulty by designing a series of iron-carbon-nickel alloys having the same  $M_s$  temperature, but well below room temperature ( $-35^\circ\text{C}$ ); in this way, the specimens could be conveniently prepared in the austenitic condition and then subcooled to produce virgin martensites for measurement or testing at subzero temperatures without any inadvertent aging. That procedure



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has now led to a stream of investigations around the world on the aging and tempering of initially virgin ferrous martensites.

However, in this approach, the virgin martensites are invariably associated with retained austenite. Peter was the first to establish a direct method for extrapolating bulk properties back to zero retained austenite, or up to 100% martensite. By systematic treatments, he was able to plot bulk measurements made at subzero temperatures as a function of the volume percent of martensite, thus making the aforementioned extrapolations feasible.

But on aging and testing over a range of subzero temperatures, Peter noted that aging sets in even at temperatures as low as  $-60^{\circ}\text{C}$ . For example, Figure 1 illustrates how the hardness at  $-195^{\circ}\text{C}$  varies with aging temperature for Fe-C-Ni alloys with increasing carbon content<sup>(1)</sup>. This was the first time it was clearly demonstrated that aging processes in virgin martensites can start at surprisingly low subzero temperatures, and that such aging causes an increase in hardness, superimposed on the hardness of the virgin martensite. Also, this age hardening reaches its maximum at or somewhat above room temperature and, therefore, plays a role in the observed strength of as-hardened steels when typically quenched to room temperature. This aging increment is now attributed to the diffusion-dependent clustering of carbon atoms within the martensite, prior to any carbide precipitation which might otherwise be characteristic of the conventional first stage of tempering. All of these phenomena, treated in Winchell's early MIT paper, have provided a firm foundation for much of the subsequent research on the aging and tempering of ferrous martensites

up to the present time; it will certainly show through in several of the papers to be presented during this Symposium.

Another milestone was reached in the 1980 Winchell paper<sup>(2)</sup> with P. C. Chen on "Martensitic Lattice Changes During Tempering." That outstanding contribution could easily have formed the keynote lecture for this Symposium. In the 1980 paper, a precision x-ray diffractometer was constructed to study the aging and tempering of a 1%C-18%Ni martensite, with an  $M_s$  temperature of  $-60^\circ \text{C}$  and initially in the virgin condition. These experiments were carried out in remarkable detail. Figure 2 shows the changes in the tetragonal martensite (002) peak profile after aging or tempering at closely spaced temperatures from  $-45$  to  $+450^\circ \text{C}$ . The same thing was done for the (200) and (020) peak profiles. Each of these peaks was then carefully analyzed for interplanar spacings, integrated intensities, and half-maximum peak widths.

Figure 3 summarizes the results for the (002) peaks. Note the decrease in integrated intensity well before the (002) interplanar spacing begins to change. This is taken to be evidence of an increase in the mean-square displacements of the iron-atoms due to clustering of the carbon atoms in the martensite, but still staying within the original set of octahedral sites. Also, we see the early appearance of low-tetragonal martensite, labelled C, in contrast to the high tetragonality of the original martensite, labelled M, but the latter has now begun to decrease in tetragonality. At first, the axial ratio of the C phase is less than unity (i.e. the 002 spacing is smaller than the spacing of cubic ferrite), but the axial ratio soon increases to slightly greater than unity. This finding, entirely new and only revealable by the highly sensitive techniques applied to the problem,

led the authors<sup>(2)</sup> to conclude that the low tetragonality is due to coherency-strain effects between precipitated carbide particles and the adjacent carbon-depleted matrix. With further aging, the original M (002) peak broadens, while the new C (002) peak (which is very broad as first detected) progressively sharpens and eventually becomes cubic when the coherency is lost.

Chen and Winchell<sup>(2)</sup> called this early ( $\sim 50^\circ \text{C}$ ) carbide a transition precipitate; it corresponds to the beginning of the conventional first stage of tempering. It also appears that, in the tempering range of 50 to  $100^\circ \text{C}$ , changes occur in the proportions of orientation variants of the martensitic plates, perhaps because of internal twin-interface movements. This signifies the occurrence of subtle plastic flows during early tempering which could bear on the microcracking problem in hardened steel.

The two examples of Winchell-inspired research which are highlighted here serve to demonstrate the essence of Peter's professional approach to life: original ideas, thoughtful planning, elegant experimentation, careful analysis of results, and conclusions drawn with utmost integrity. And along with all that, as many of us will know, he was also a most considerate human being in arguing differences of opinion.

We shall long remember Peter Winchell. This Symposium and the publication of its papers will certainly help make that memory secure. But in addition, we have prepared a further remembrance of this day in the form of an original piece of metallurgical art, called "Martensitic Impressions." And I am now privileged to present it to Barbara Winchell. The inscription reads:



*"This esthetic conception of "Martensitic Impressions" was designed and fashioned by Anthony J. Zona of the Department of Materials Science and Engineering at MIT, in memory of Peter G. Winchell of Purdue University who died at the height of his world-renowned metallurgical career on 12 January 1981. The sculpture is being presented to the Peter Winchell Family in the name of his numerous colleagues and students, who are now here both in body and in spirit, and who are grateful for having known him, for having studied under him, and for having benefited from his lasting research.*

*"It is especially fitting that this memorialization can take place at the TMS Symposium on the Tempering of Steel, which bears the unique hallmark of Peter Winchell and his good works."*

*Presented in  
Louisville, Kentucky  
October 12, 1981*

#### Acknowledgments

In opening this Symposium on the Tempering of Steel, dedicated to Peter G. Winchell, I am most grateful to the Office of Naval Research for its long-term support of research at MIT on martensitic transformations and tempering, which included Peter Winchell's doctoral thesis submitted in 1968. The continuing ONR Contract at MIT is No. N00014-81-K-0013.

### References

1. P. G. Winchell and Morris Cohen: Trans. ASM 55 (1962) pp. 347-361.
2. P. C. Chen and P. G. Winchell: Met. Trans. A 11A (1980) pp. 1333-1339.

### Captions

- Figure 1. Hardness at  $-195^{\circ}\text{C}$  of iron-carbon-nickel martensites after aging for 3 hr. at temperatures plotted<sup>(1)</sup>.
- Figure 2. 002 peak profiles for martensite (0.98C-18Ni) formed in a single crystal of austenite and aged/tempered at successively higher temperatures as indicated (isochronal times = 1 - 2 1/2 hr.)<sup>(2)</sup>.
- Figure 3. (a) Interplanar spacing, (b) integrated intensity (I.I.), and (c) half-maximum width of 002 martensite (0.98C - 18Ni) peak as a function of aging/tempering temperature; based on peak profiles in Figure 2.<sup>(2)</sup>

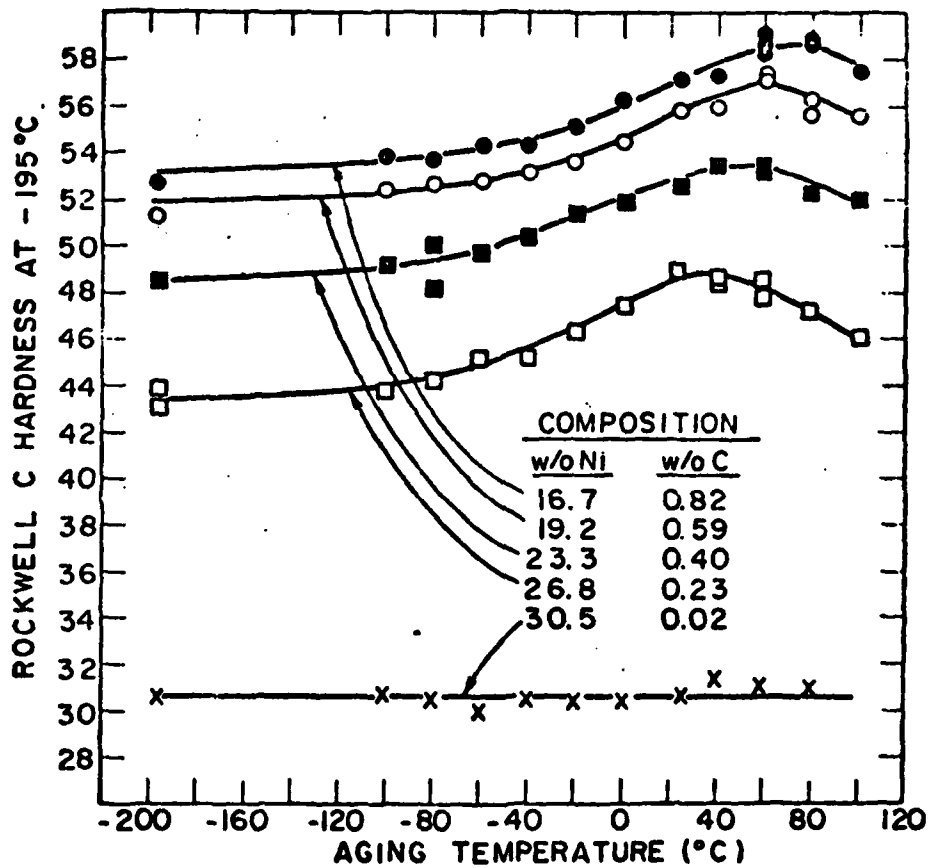


Figure 1

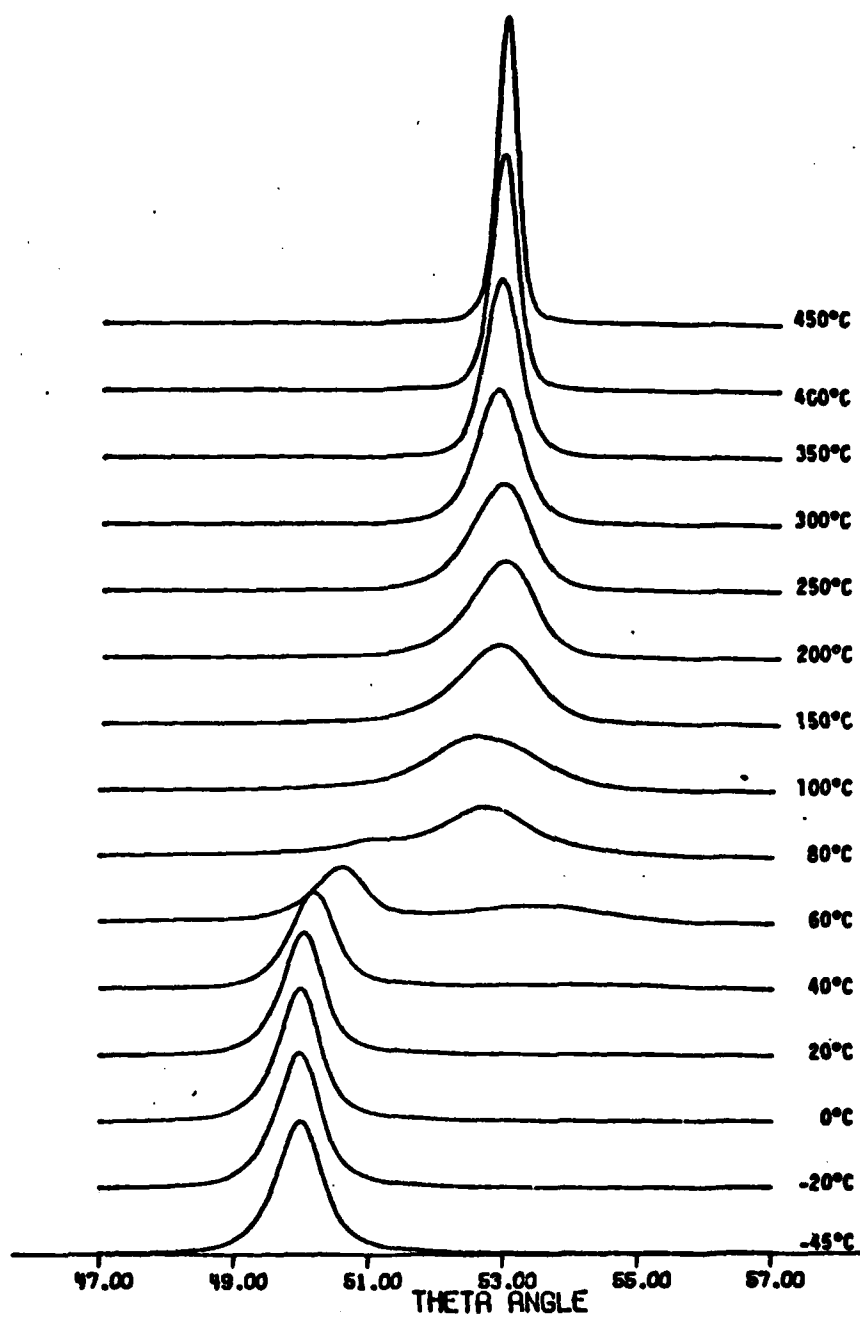


Figure 2

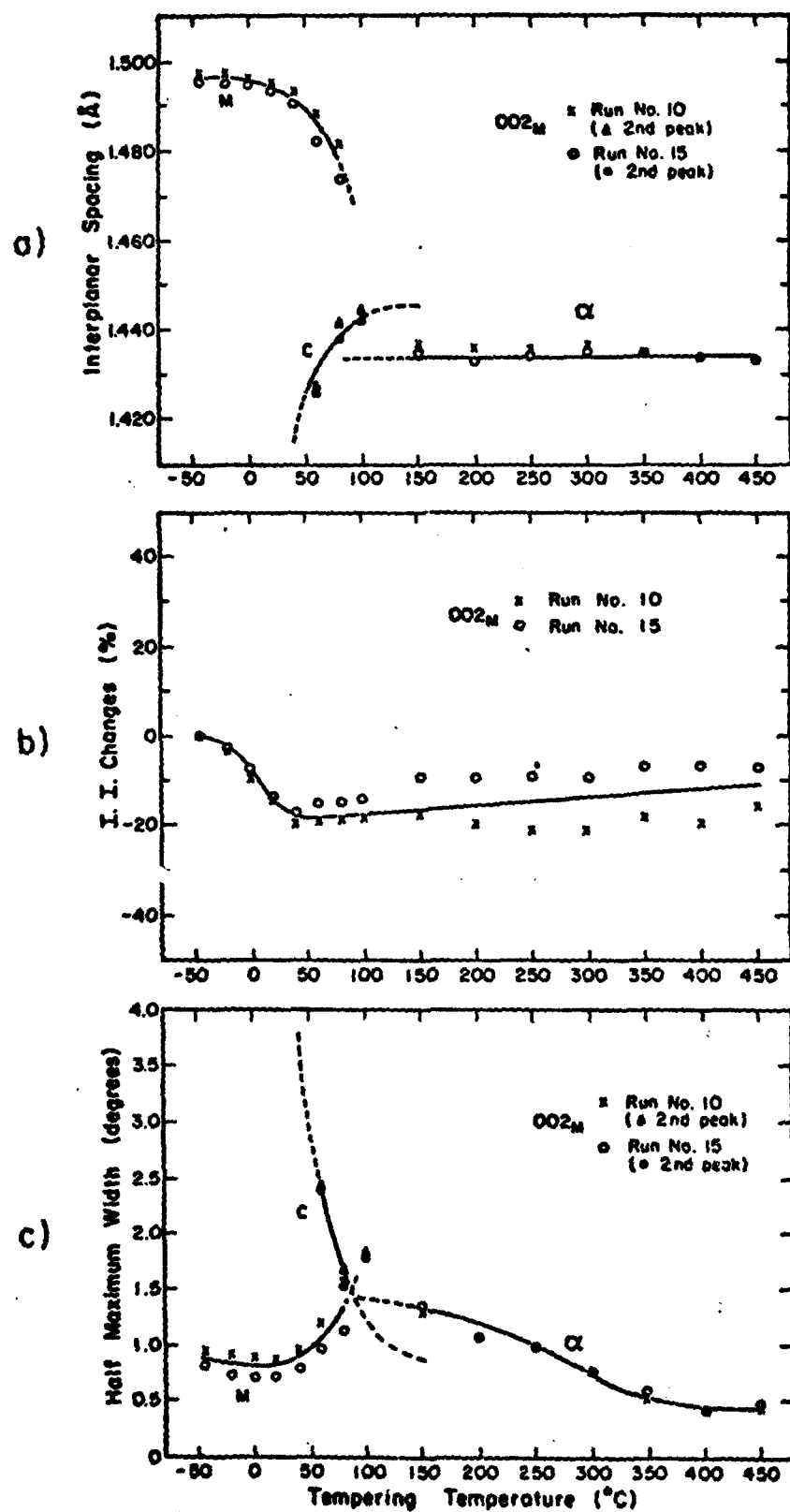


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